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CYGNUS PERFORMANCE ON SEVEN SUBCRITICAL EXPERIMENTS *

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Abstract

The Cygnus Dual Beam Radiographic Facility includes two identical radiographic sources - Cygnus 1 and Cygnus 2. Cygnus is the radiography source used in Subcritical Experiments (SCEs) at the Nevada National Security Site (NNSS). The machine specifications are: Electric 2.25 MV, 60 kA, 60 ns; Radiation 4 Rad, 1 mm, 50 ns; Operation single shot, 2-shots/day. Cygnus has operated at the NNSS since February 2004. In this period, it has participated on seven SCE projects - Armando, Bacchus, Barolo A, Barolo B, Pollux, Vega, and Ediza.

SCE projects typically require over a hundred preparatory shots culminating in a single high-fidelity or SCE shot, and typically take over a year for completion. Therefore, SCE shots are high risk and high value making reliability and reproducibility utmost priority. In this regard, major effort is focused on operational performance. A quantitative performance measurement is valuable for tracking and maintaining Cygnus preparedness. In this work, we present a new model for analysis of Cygnus performance. This model uses x-ray dose distribution as the basis for calculation of Reliability, Record, and Reproducibility. It will be applied both to long-term (historical) and short-term (readiness) periods for each of the seven SCEs.

I. CYGNUS DUAL BEAM RADIOGRAPHIC FACILITY

The Cygnus Dual Beam Radiographic Facility consists of two identical radiographic sources, Cygnus 1 and Cygnus 2, each with the following specifications: 4-rad dose at 1 m, 1-mm spot size, 50-ns pulse length, and 2.25-MeV endpoint energy

Each Cygnus machine has 5 major components as shown in Figure 1: Marx Generator, Pulse Forming Line (PFL), Coaxial Transmission Line (CTL), 3-cell Inductive Voltage Adder (IVA) [1], and Rod Pinch Diode (RPD). Each machine is independently triggered and may be fired in completely separate tests (staggered mode), or in a single test in which both machines are fired with sub-second separation between pulses (dual mode). Cygnus operates as a single-shot machine since on each pulse the diode electrodes are destroyed. After each shot, the diode is vented to atmosphere, cleaned, and new electrodes are inserted. Normally there are two shots per day on each machine.

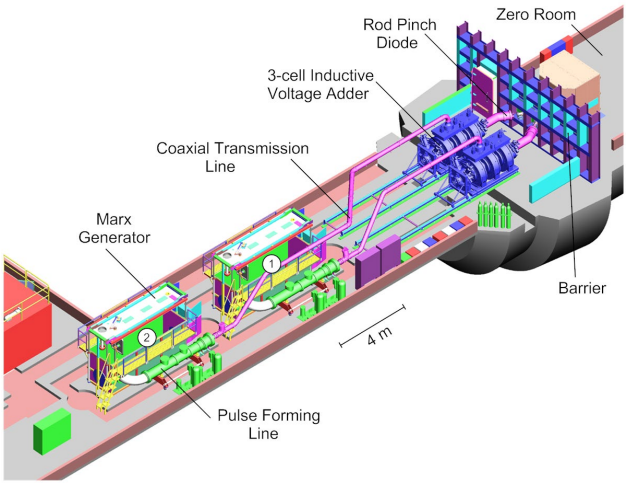

Figure 1. Cygnus Dual Beam Radiographic Facility.

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Cygnus uses a "Rod Pinch Diode" geometry [2] where the cathode consists of an aluminum plate with an on-center aperture, and the anode is a tungsten rod which threads the aperture.

LiF thermoluminescent dosimeters (TLDs) are the primary diagnostic for Cygnus performance [3]. The dosimeters have 1 inch thick aluminum on-axis shielding, and dose is scaled for a distance of 1 m.

II. SUBCRITICAL EXPERIMENTS

Cygnus 1 and 2 have been used for radiography of subcritical experiments at the Nevada National Security Site (NNSS) since 2004. The Cygnus Facility is located in an underground tunnel complex named U1a. The Cygnus sources were developed as a primary diagnostic for these experiments. The first subcritical experiment to utilize Cygnus (Armando) was executed on May 25, 2004. Since Armando, several other subcritical experiments have been executed in front of Cygnus as shown in Table 1. Other testing categories have also been performed such as basic physics experiments and plutonium density calibrations. Inherently, subcritical experiments are single-shot, high-value events.

Table 1. SCE Dates.

SCE Project	Execution Date
Armando	May 25, 2004
Bacchus	September 15, 2010
Barolo A	December 1, 2010
Barolo B	February 2, 2011
Pollux	December 5, 2012
Vega	December 13, 2017
Ediza	February 13, 2019

III. PERFORMANCE MODEL

A quantitative performance measurement is valuable for tracking and maintaining Cygnus preparedness. Accordingly, the following model has been developed.

A grading tool for Cygnus shots has been defined as shown in Table 2. It uses percent of design dose (4.0 Rad) as a standard for performance. As a "rule of thumb" all shots above 2.8 Rad produce useable radiographs.

Table 2. Grade Definitions.

Grade	Range (% of Design)	Range (Rad)
A^+	> (+10%)	> 4.4
A	(-10%) to (+10%)	3.6 to 4.4
B	(-20%) to (-10%)	3.2 to 3.6
C	(-30%) to (-20%)	2.8 to 3.2
F	< (-30%)	< 2.8

There are three key metrics to gauge Cygnus performance – Reliability, Record, and Reproducibility.

These metrics all incorporate the grading tool. They are visually depicted in Figure 2 as applied to a sample Cygnus dose distribution.

Reliability is the percentage success rate using 2.8 Rads as the "cutoff value" (uses all shot grades). Record is the population mean, and Reproducibility is the population deviation (uses only A and A^+ shot grades).

For an SCE there are three meaningful shot periods as shown in Table 3.

Table 3. SCE Shot Periods

# Shots	Period Description
100	Historical
10	Readiness
1	SCE

The Historical and Readiness Periods include contiguous shots leading up to the SCE shot, and are long and short term predictors of success on the SCE shot. The long/short term distinction is made to incorporate a timeliness factor into the performance assessment.

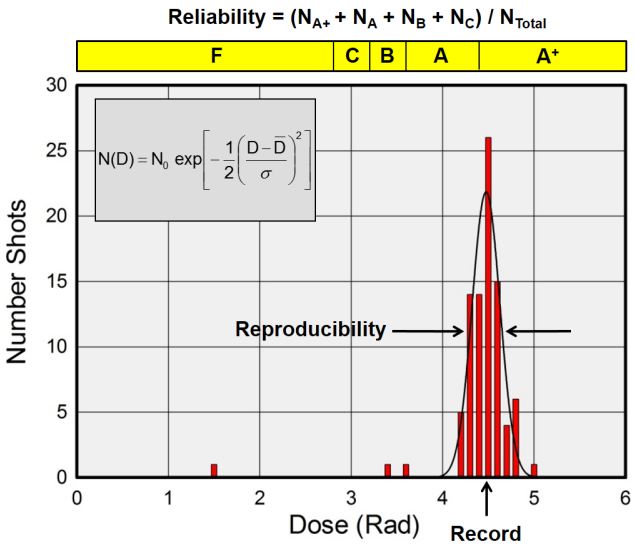

Figure 2. Performance metrics.

IV. DOSE DISTRIBUTIONS

Due to schedule limitations a reduced number of preparatory shots (44) was devoted to the first SCE, Armando. All the other SCEs used 100 preparatory shots. Dose distributions for the last five SCE projects are given in Figures 3 and 4. All shots use identical pulsed power settings and diode geometry. Dose bins are 0.1 Rad wide.

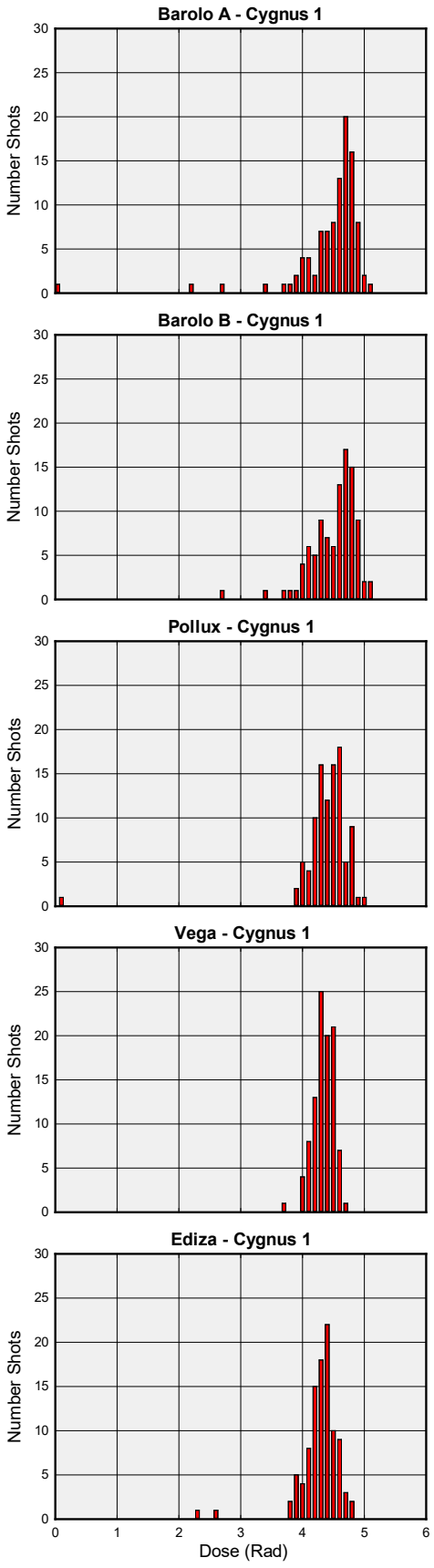

Figure 3. Cygnus 1 dose distribution.

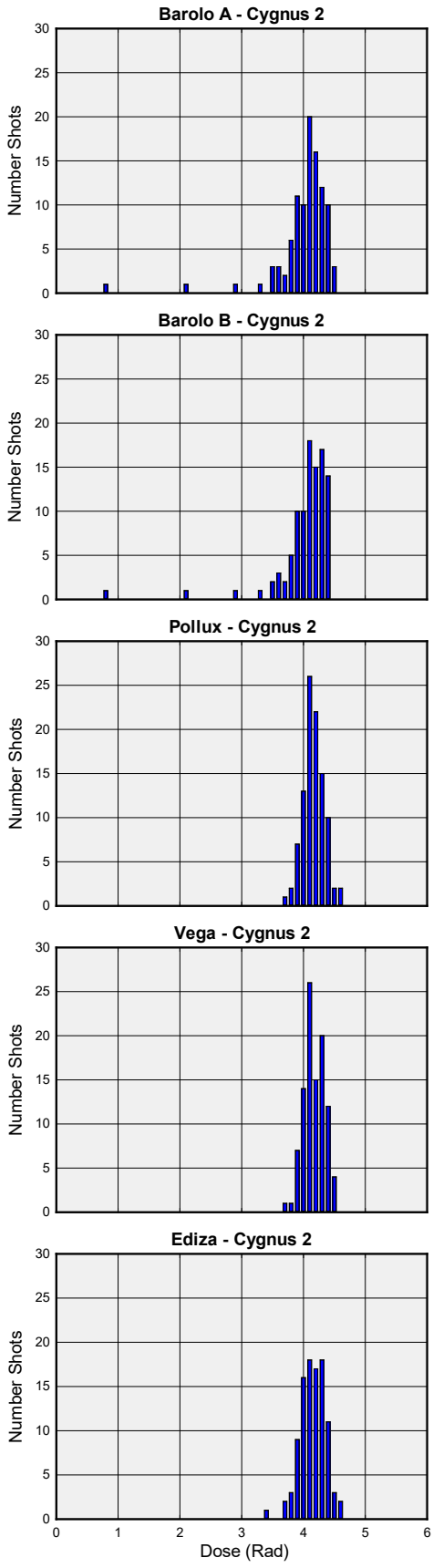

Figure 4. Cygnus 2 dose distribution.

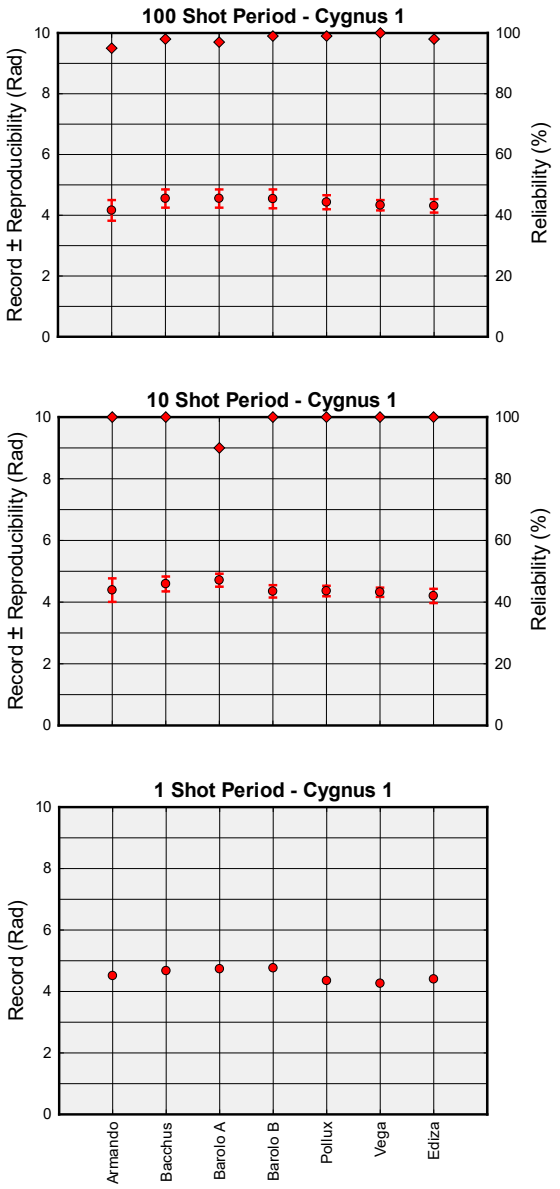

Figure 5. Cygnus 1 performance summary.
Legend: ●Record ◆Reliability

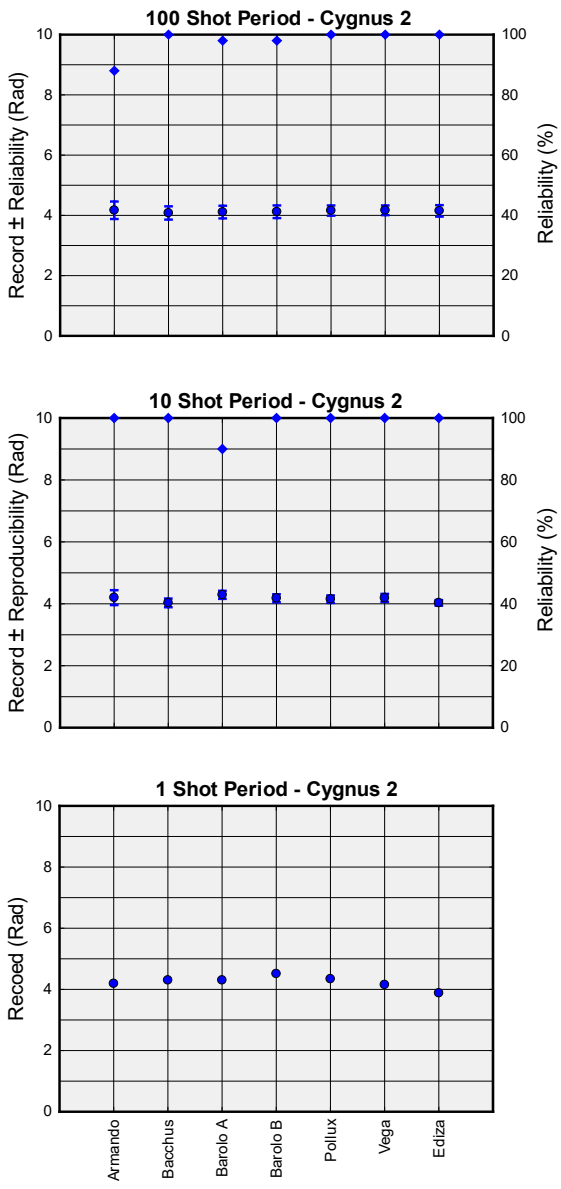

Figure 6. Cygnus 2 performance summary.
Legend: ●Record ◆Reliability

V.PERFORMANCE SUMMARY

Performance results for the seven SCE projects, corresponding to all three shot periods, are given in Figures 5 and 6. Design specifications for Reliability, Record, and Reproducibility are: 99.5%, 4.0 ± 0.4 Rad. With infrequent and minor exceptions, all three performance metrics are in excellent agreement with design specifications on both machines. The new performance model demonstrated here provides a valuable quantitative evaluation of due diligence for the high stakes SCE program.

VI.REFERENCES

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